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## TITLE

### TENSIONED PIPE SUPPORT

5

## RELATED APPLICATION

This application is a continuation in part of pending application Serial No. 10/770735 entitled "Apparatus and Method for the Repair and Stabilization of Underground Pipes" filed February 3, 2004, and pending application Serial No. 10 10/182,889 entitled "Apparatus, Methods, and Liners for Repairing Conduits" and filed February 2, 2001.

## BACKGROUND OF INVENTION

### 15 1. FIELD OF THE INVENTION

The present invention relates to an "insitu" method to repair underground pipes and conduits to reduce or eliminate ground water infiltration while stabilizing the proximate ground formation surrounding the pipes.

### 2. BACKGROUND OF THE INVENTION

20 The Clean Water Act has mandated that ground water infiltration into our sewer systems be substantially reduced or eliminated. Many methods of repair have been devised over the last thirty years. Some of those repair methods include slip lining, pipe bursting, cured in place pipe lining (CIPP), fold and form thermoplastic lining, spot repairs, as well as the traditional dig and 25 removal/replacement of pipelines.

It is a known fact that the federal interstate highway system has met and in certain cases exceeded its design life by controlling or reducing incidents of pavement collapse, settling and irregular surfaces. This has been achieved with the development of techniques for the injection of grouts or placement of epoxy 30 patches. In addition, the concrete repair industry has developed and refined the utilization of expandable structural closed cell foams to raise, level and stabilize concrete slabs, foundations, pavements and buildings.

The "insitu lining" repair of pipes has been the most effective alternative to pipe "dig and replacement" for many year. Occasionally an existing annular space or void adjacent to the outside surface of the pipe or conduit has been injected with gelatinous grout materials to eliminate water infiltration into the pipe.

5 This repair has been only temporary since the gelatinous material is not dimensionally stabile and often requires later replacement. The grout is not capable of stabilizing the ground around the pipe even if the entire annular space is filled with the gelatinous grout. The lack of stability and support can result in additional stress on the pipe structure, with eventual degradation of the pipe and  
10 resulting water infiltration.

Injection of expanding closed cell foams has seldom been used to repair pipes. Where the closed cell foams have been used to level or reinforce pipe sections, there has been migration of the foam into the pipe/conduit joint that, if left in place, can cause an occlusion or blockage. When this migration into the  
15 interior diameter of the pipe does occur, a cutting or grinding device must be inserted as a subsequent step to remove the excess foam.

Another issue is the typical foams being used today are polyurethane's which often contain isocyanate, a groundwater contaminant. Some research has been conducted to determine if the closed cell foam chemistry could be used with  
20 grout packers. The blowing agents in the foam, however, create a near immediate reaction that will not allow the annular space to be filled with the foam.

There are hybrid polyester/urethanes expandable closed cell foams that could be used and avoid isocyanate. However, these alternate foam formulations have not been well suited to curing in the *ambient* underground soil  
25 conditions.

Another method for repair of pipes has been to excavate a damaged pipe section and wrap the outer pipe wall with a high tensile strength material having an elasticity maintaining the band in contact with the pipe. See for example US Patent No. 4,700,752 of Norman C. Fawley. Another method has been to repair  
30 or reinforce a pipe section by wrapping the outer pipe wall with a composite material having a multiplicity of high tensile strength filaments encapsulated in a

resin matrix. The wrapping material is manufactured in a coiled structure and installed by deflecting portions of the material into an uncoiled configuration and then wrapping those portions of the material around the pipe. The material may be applied with an adhesive coating on the pipe surface and between each coil layer. See for example Fawley, US. Patent No. 5,683,529 and 5,677,046.

The measure of physical properties of materials relevant to the present invention include ASTM D1621 Compressive Strength, ASTM D790 Flexural Strength, ASTM D1622 Density, ASTM C 273 Shear Strength, ASTM D 2126 Dimensional Stability, ASTM D696 Coefficient of expansion, ASTM D 543 Chemical Resistance, and ASTM D 2842 Water Absorption.

### SUMMARY OF INVENTION

In situ pipe repair methods have been developed utilizing techniques for heat assisted cured in place pipe lining ("CIPP") utilizing epoxy repair materials.

This technology has allowed the use of styrene free thermosetting or thermoplastic resins in an impregnated ("prepreg") composite repair material that is cured with an expandable and heatable bladder. Thermoset resins are curable resins that can be introduced or impregnated into a fibrous repair material. The curing of the resin results in a change of phase of the resin from a liquid to a solid. As a solid, the repair material continues to have the fiber structure. This technology has been adapted for use in the repair or sealing of pipes or conduits, including sewer mains and lateral lines, ("pipes) and the junctions or interfaces of multiple pipelines.

This invention teaches the use of this technology in combination with the injection of chemical reactants creating expanding closed cell foam ("foaming liquids") for stabilization of the surrounding ground proximate to the underground pipes. The heat assisted CIPP mechanisms and techniques for interior pipe repair thereby allow the use of more environmentally friendly foaming liquids than feasible in ambient conditions to stabilize the ground surrounding the pipe. The inflated bladder can provide a heat source for curing of the resin of the prepreg repair materials, closed cell foaming liquid resin and limiting resin redistribution,

and a supporting mechanism for maintaining the pipe diameter and to prevent infiltration of the foam or foaming liquid into the pipe interior.

The invention also teaches use of the expandable bladder alone within the inside diameter of the pipe in combination with the injection of foaming liquids proximate to the exterior of the pipe surface. The invention also teaches use of an expandable and heatable bladder within the inside pipe diameter to assist in the cure of the injected foaming liquids.

The present invention provides for an improved method of stabilizing the adjacent underground soils or formation around the pipe, minimizing ground water infiltration into the pipe, while repairing the host pipe/conduit or connection. The invention also minimizes exfiltration of sewerage from the pipe. Such exfiltration is a problem particularly when the pipe system is fully charged during a rainfall event.

This invention also teaches the use of an elastically coilable and radially outward expandable material to support and repair pipes. The teaching of this invention includes use for the internal repair of the pipe wall. This may be used in conjunction with other embodiments of the invention such as soil compaction and stabilization using closed cell foam and resin cured pipe wall repair materials.

The invention also teaches use of a exterior tensioned support exerting a radially compressive force that may be used in conjunction with the interior support, an interior inflated bladder, or alone as a heat source combination with heat responsive repair materials.

Other benefits of the invention will also become apparent to those skilled in the art and such advantages and benefits are included within the scope of this invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention. These drawings, together with the general description of the invention given above and

the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

Figure 1 illustrates a typical sewer pipe and lateral connection.

Figure 2 illustrates typical defects necessitating repair of a sewer pipe and  
5 sewer pipe connection.

Figure 2A represents a cross sectional view of a defective pipe.

Figure 3A illustrates the prior art use of foaming liquids.

Figures 4A and 4B illustrate the use of the inflatable bladder in  
combination with injection of foaming liquid.

10 Figure 5 illustrates the pipe repair equipment utilized with simultaneous repair of the pipe interior and ground stabilization.

Figures 5A through 5E and 5G further illustrate the pipe repair equipment.

Figure 6[G] illustrates a detail of the woven repair material for a pipe  
interface repair.

15 Figure 7 illustrates a woven repair material utilized in one embodiment of the invention.

Figures ~~10, 10A and 10B~~ 8 and 8A are cross sectional views of a hybrid woven repair material.

Figures ~~11A and 11B~~ 9A and 9B are additional cross sectional views of  
20 other hybrid fiber woven repair material.

Figure ~~12~~ 10 is an illustration of the braided repair material.

Figure ~~12A~~ 10A is an illustration of a rochelle knit.

Figure ~~13~~ 11 is an illustration of the helically wound repair material.

Figure ~~14~~ 12 is an illustration of multiply aligned pipe segments.

25 Figure ~~14A~~ 12A is an illustration of mis-aligned pipe segments.

Figures ~~15 and 15A~~ 13 and 13A illustrate the realignment of pipe segments utilizing the invention.

Figures ~~16 and 16A~~ 14 and 14A further illustrate the realignment of pipe segments utilizing the invention.

30 Figures ~~17A through 17G~~ 15A through 15H provide a cross sectional view of the operation of one embodiment of the invention.

Figures ~~18A through 18C~~ 16A through 16C illustrate cross sectional views of the tensioned support.

Figure ~~18D~~ 16D illustrates a prior art method.

Figure ~~19~~ 17 illustrates the relationship of the pipe surface to the resin impregnated tensioned support with electrically conductive fibers for heating.

Figures ~~20A and 20B~~ 18A and 18B illustrate the combined application of internal and external tensioned supports.

### DETAILED DESCRIPTION OF THE INVENTION

10 The above general description and the following detailed description are merely illustrative of the subject invention and additional modes, advantages and particulars of this invention will be readily suggested to those skilled in the art without departing from the spirit and scope of the invention. The teaching of this invention will be understood to be applicable for both the repair or support of  
15 sewer pipe connecting interface, as well as for linear and non linear pipelines.

Figure 1 illustrates typical underground sewer pipe configuration that can be the object of repair by the method and apparatus of this invention. The pipes comprise a lateral line 500 typically emerging from a single building or home (not shown). The lateral line is installed for gravity drainage 640 into a collector  
20 sewer or sewer main pipe 200 through a connection or connecting interface 400. Sewerage is gravity conveyed 650 through the diameter 300 of the sewer pipe 200. The lateral pipe and the main sewer pipe each has a longitudinal axis 350. However, over time, the orientation of the individual pipe segments may change from the original longitudinal axis, creating a "non linear" pipe. (Reference is  
25 made to Figures 14 and 14A.) Non linear pipe can also, of course, include curved pipe.

The lateral pipeline and the main sewer pipe are typically comprised of separate segments jointed by a male-female type connecting end flange. The female flange component 210 and corresponding male component 211 are  
30 illustrated in Figure 2. It will be appreciated that the sewer pipe system is buried

within the ground 100 beneath the ground surface 105. The system can be accessed through various ports such as manholes (not shown).

Figure 2 is a cross sectional schematic of the sewer pipe 200 along the longitudinal axis 350. The direction of the gravity flow of sewerage is shown by vector arrow 650. The male 211 – female 210 coupling of the separate sewer pipe sections is also illustrated.

Figure 2 illustrates a common problem experienced with sewer pipe systems. Due do a variety of causes, including the aging of the pipe material, ground shifts or settlement, etc., ground water 175 migrates into the sewer pipes 200. This can cause the exfiltration of sewerage into the surrounding soil or ground water, particularly when the sewer lines are heavily charged, such as during a significant rain event. Alternatively, the infiltration of ground water can burden the sewerage treatment system thereby increasing treatment costs or causing inadequate treatment. (In addition to the obvious environmental damages that may result from inadequate sewer treatment, the inadequate treatment may result in fines and other damages being imposed by regulatory agencies.)

The infiltration of ground water often carries particles of the adjacent soil 100 into the sewer system, which can over time result in voids 150 being created surrounding the pipe 200. The creation of voids or increased interstitial spaces results in groundwater collecting proximate to the pipe. This groundwater can then pass, i.e., infiltrate, into the sewer pipe wall 250 through the cracks 240 or holes 255. It can also pass through defects, such as gaps, in the junctions of each pipe segment 210 211.

Figure 2A is a schematic illustration across the longitudinal axis 350 of a section of the damaged sewer pipe 200 beneath the ground surface 105 and adjacent void 150 in surrounding soil 100. Also illustrated are the pipe diameter 300 and cracks 240 and voids 255 through the thickness 251 of the pipe wall 250. The several vector arrows 175 illustrate the flow of ground water from the soil 100 into the void 150 surrounding the pipe 200 and through the cracks 240 and holes 255 within the sewer pipe wall 250. It will be appreciated that the



voids intended to be remedied by the subject invention need not be of the large size depicted in these illustrations. Further, it will be appreciated that the subject invention is not limited to repair holes or cracks in pipes, but can be used to seal connections (or "couplings") between pipe segments, or between pipe lines, e.g.,  
5 a sewer collection pipe and one or more lateral pipes convey waste ("sewerage") from individual residences, etc.

Use of close cell expandable foams have been used to fill subsurface voids in soils, including use to mechanically raise objects supported by the soil. This has been used in foundation leveling, etc., as taught by Patent Nos.  
10 4,567,708, 6,521,673 and 6,634,831. However, this technology has important limitations for use in filling voids surrounding sewer pipes or sealing/repairing pipe defects. One disadvantage is the infiltration of the closed cell foam into the interior pipe diameter (through which sewerage is intended to flow), thereby creating an occlusion that must be mechanically removed to prevent blockage of  
15 the sewage flow. In addition, the expansive pressure of the closed cell foam (useful in filling or compacting the soil particles or interstitial voids within the soil or between the underground soil and the structure, e.g., sewer pipe or lateral collector, to minimize water collection/infiltration), may also further damage the pipe wall.

20 Figure 3A is a schematic illustration across the longitudinal axis 350 wherein closed cell foam 600 is injected from the ground surface 105 through the injection mechanism 650 into the void 150 within the ground 100 adjacent to damaged sewer pipe wall 250. The foam equipment combines static head mixers 650 with a strong insertion device attached to pumps (not shown) located  
25 at the ground surface 105. The cross section view illustrates the closed cell foam filling the void 150 and infiltrating into the diameter 300 of the sewer pipe 200 through the holes 255 and cracks 240 within the pipe wall 250. The infiltrating foam is shown to create obstructions 337 338 339 within the pipe diameter 300. It will be appreciated that the foam may not fill the entire void 150, perhaps due  
30 to the presence of entrapped ground water (not shown), thereby allowing for the continued collection of ground water proximate to the repaired pipe. The

migration of foam into the pipe can ultimately block the pipe diameter 300 unless a cutter/grinder unit (not shown) is inserted into the pipe and the occlusion is removed. It will be appreciated that it is desirable to avoid this time consuming and expensive step.

5 One embodiment of the apparatus and methods taught in this specification is the advantageous use of techniques for installing a thermally responsive pipe repair material (thermoset or thermoplastic impregnated liner) within the interior diameter of a sewer pipe *in combination with* injection of expanding closed cell  
10 foam proximate to the outer diameter of the sewer pipe. The repair material for the interior pipe diameter may be of a variety of structures, including a structure being defined as an arrangement of fibers such that the repair material has similar dimensions as the pipe diameter or pipe interface to be repaired or sealed. The arrangement of fibers further allows the repair material to be flexible and seamless. Figure 7 9 illustrates an example of a woven structure 410 having  
15 a longitudinal axis 350. In the illustration, fibers 118 119 are intersecting at a variable angles 125. It will be appreciated that the composition of fibers and fiber architecture can be varied, as shown in the cross sectional illustrations along the axis AA in Figures 8, 8A, 9A and 9B 10, 10A, 11A and 11B discussed later. In a preferred embodiment utilizing the repair material, the material includes a resin  
20 having a viscosity. An additive may be provided to alter the resin viscosity. It will be appreciated that it may be advantageous to increase resin viscosity to retard resin redistribution within the fiber repair material or fiber liner prior to and during the installation process.

A flexible and inflatable bladder is inserted within the pipe diameter. The  
25 bladder serves as a mold to press and hold the repair material to the interior surface of the pipe during the repair process. The inflated bladder, which, in an alternate embodiment of the invention, can be used without the resin impregnated repair material or liner, also minimize the migration of the chemical reactant or resulting foam injected into the underground soils proximate to the  
30 pipe. The migration of chemical reactants or foam can result in occlusion or

obstruction of the pipe diameter. This would obviously hinder the flow of sewerage through the pipe.

The fibrous construction of the repair material, or the components of the inflatable bladder, can include conductive fibers, e.g., carbon fibers, that can be  
5 connected to an electrical power source. These conductive fibers, when powered with electric current, may provide electrically resistive or impedance heating (termed herein as "resistive heating") directly through or immediately proximate to the thermosetting resin contained in the repair material. The combined and concurrent pressing of the resin impregnated fibers to the inner  
10 pipe wall surface with the heating of the thermosetting resin allows an improved repair and support. The addition of heat, in contrast to ambient conditions, allows more rapid curing. Further, this allows the bladder to remain in place as a mold pressing the repair material for a greater portion of the cure and minimizes the degradation of the repair by resin redistribution. It will be appreciated that the  
15 use of the expanding and heatable bladder also minimizes the formation of "annulae" between the interior pipe wall surface and the liner.

Further, heat from the bladder or repair material is also available to radiate through the thickness of the pipe wall to facilitate to the cure of the foaming liquid exterior to the pipe wall. Curling of the foam creates a phase change in the foam  
20 to a closed cell solid. The closed cell foamed solid can compact the underground proximate to the pipe, decrease voids or interstitial space containing infiltrating ground water, as well as support and seal the pipe and pipe junctions.

The availability of the proximate heat source also allows use of alternate foaming agents, particularly agents not containing isocyanates. It will be  
25 appreciated that isocyanates are considered to be a source of environmental contamination. These alternate reactants include hybrid polyurethane or polyester/polyurethane blend resin, and epoxy resins combined with diluents, catalysts, blowing agents and surfactants, an acrylimide, and cementitious slurry.

Figure 4A is a schematic cross sectional illustration along the longitudinal  
30 axis 350 illustrating an embodiment of the method and apparatus of the invention by placing a flexible and inflatable heating bladder 450 inside the pipe diameter

300. The bladder is placed in the area of the pipe having holes 255 or cracks 240 in the pipe wall 250. In this manner, the inflated bladder can provide support to the damaged pipe and facilitate maintaining the pipe diameter 300 during the repair process. The bladder may have resistively heatable sub-components to  
5 facilitate the curing of the chemical reactant injected proximate to the exterior pipe wall surface 254.

Figure 4B is a schematic illustration across the longitudinal axis 350 of the pipe after inflation of the bladder 450. The bladder, if used as a heat source, may assist in the curing of the closed cell foam. It will restrain the injectible  
10 chemical reactant and resulting foam 600 from permeating the pipe through coupling connectors (211 210 of Figure 2) or cracks 240 or holes 255 in the pipe wall 250. The migration of foam is illustrated in Figure 3A by the multiple vector arrows. The liner 410 (not shown) may be placed over the bladder for reinforcement or to minimize binding of the bladder to the cured foam.

15 An embodiment of the invention includes the use of resistive energy as a source of heat for curing the injected chemical reactant, as well as to block the migration into the pipe diameter. This heat curing can be accomplished in combination with the placement of a resin impregnated ("prepreg") repair material within the pipe diameter. As mentioned above, the repair material or the flexible  
20 bladder may contain electrically conductive fibers. Alternatively, the fiber can be a combination of electrically conductive fibers and non-conductive fibers, which include polyester, glass, aramid, and quartz fibers, and thermoplastic fibers such as, but not limited to polypropylene, nylon and polyethylene.

The repair process is illustrated in Figures 4A, 4B and Figures 15A-H 47A-  
25 G where one skilled in the respective arts observes that there are similarities in both systems, which require 50 K.W. generators and 150 CFM compressors and various cables and hoses. The present invention demonstrates the synergies between the two systems, which eliminates boiler trucks, and on site mixing and impregnation of repair material.

30 An alternative embodiment that can be used alone or in conjunction with the bladder is inserting an elastically collapsible and radially expandable material.

This can be of differing materials, including metal. Important features will be the elasticity, high strength and shape memory, thereby allowing the material to be wound into a tighter coil with a more compact diameter or shorter radius and expansively returning to its original shape. Upon release of the winding energy,  
5 the material relaxes and returns to its original coil diameter. This relaxed diameter will be greater than the internal pipe diameter, thereby causing a relative uniform radial outward pressure force.

It will be appreciated that the mechanism will maintain an open annulus within the pipe thereby allowing the continued passage of fluids through the pipe.  
10 Of course this can permit the relaxed coil to remain in place during the curing process, and thereafter without interruption of service.

This invention addresses the cause and repair of connection offsets or misalignment of pipes and conduits. The misalignment of an originally installed linear pipe may result from faulty bedding surrounding the pipe, which is not  
15 tested as it is in pressure pipe/conduit situations, and ultimately can crack or offset the joints after the pipeline is back-filled. Another cause of misalignment is the result of the movement of ground water as already discussed. While some may contend this method is redundant and more costly, one skilled in the art will easily recognize the efficiencies and safety elements of the present invention

20 This embodiment of the invention provides methods of repairing the misalignment of pipe sections 250A such as that shown in Figure 12A-44A. In this case, the non-linear conduit is buried below the ground surface 105 predominantly in a horizontal orientation as part of a pipe network, e.g., sewer system. The non-linear pipe consists of separate pipe or conduit segments 25A,  
25 25B, 25C, 25D, 25E, 25F, 25G that have moved from the original longitudinal axis 350 illustrated in Figure 12-44 to a non congruous longitudinal orientation 351 and thus does not follow a strictly linear path.

The embodiment of the method taught by this invention comprises providing the inflatable bladder dimensioned to fit within the interior diameter 300  
30 of the pipe 250A, and particularly each non-congruous pipe segment 25A, 25B, 25C, 25D, 25E, 25F, 25G. The bladder is dimensioned so as, when inflated,

presses against the interior surface of each damaged, e.g. mis-aligned, cracked or broken, section of conduit. The bladder can be made of any strong flexible material. It will be appreciated that it may be advantageous to fit the bladder with one or more layers of protective outer sleeves or liners ("liners"). The liners can provide a repair material (sometime referred to as "material structure") as discussed elsewhere herein, but may also provide protection to the bladder from sharp or jagged surfaces within the conduit sections. The bladder may be filled/inflated with fluid, such as water or air, and the effectiveness of the bladder would be compromised if the bladder was punctured.

Figure 13 and 13A 15 and 15A illustrate an embodiment of the invention wherein the bladder 450 is placed within the diameter 300 of several mis-aligned pipe segments 25A, 25B, 25C, 25D, 25E, 25F, 25G beneath the ground surface 105. Figure 15 13 illustrates the bladder with several pipe segments 25B 25E removed for clarity of illustration. The original or intended longitudinal axis of orientation 350 is also shown. It will be appreciated that the mis-alignment may be in any of the three axes of orientation (X, Y, Z).

Figure 16 14 illustrates the next step of the repair method. Multiple chemical reactant insertion ports 650 are installed from the ground surface 105 to a desired location proximate to the pipe. In the illustrated situation, the ports are installed to be beneath the mis-aligned pipe segments 25B, 25C, 25D, 25E, 25F. The goal of the repair is to push the pipe segments into closer alignment with the longitudinal axis 350. A chemical reactant is injected through the ports into the ground 100 creating the expanding foam 600. Figure 14A 16A illustrates the result of the injection of expanding thermosetting foam 600, causing pipe segments 25B, 25C, 25D, 25E, 25F to be pushed upward as shown by vector arrow 675. The inflatable bladder 450 acts as a flexible mold having a control or guiding function in the realignment of the pipe sections, particularly with regard to the continuity of the pipe diameter 300 and common longitudinal axis of orientation 350.

As suggested by the Figures 12 through 14A 14 through 16A, substantial length of pipe can be simultaneously repaired by the invention. The length of

inflatable and heatable bladder is not limited. Lengths of pipe extending from one access manhole to a second manhole may easily be simultaneously repaired by a single use of the method and apparatus of the invention.

Based upon the foregoing disclosure, it will be readily appreciated that the above method can be combined with the embodiment utilizing a repair material liner impregnated or containing a curing thermosetting or thermoplastic material to seal the pipe from the interior diameter. The repair material structure may be defined by a plurality of fibers such that the repair material is flexible and seamless. This structure is sometimes referred to as a woven "preform".

The resin may be in the form of prepreg fibers or as a resin matrix surrounding the woven structure. The resin can be a polyester resin, a vinyl ester resin, a urethane polyester resin, a urethane-vinyl ester resin, an epoxy resin or a polyurethane resin. The resin is introduced into the repair material by either injection or infusion depending on the type of resin utilized.

A flexible and seamless repair material is able to adapt and conform to the interior of the conduit. The repair material will neither bind nor wrinkle to cause obstructions to material flow in the conduit. The construction and selection of the repair material also allows it to be used in conjunction with the inflatable bladder. The repair material may be placed as an outer liner on the deflated bladder.

Next, the repair material and bladder is placed in the conduit in close proximity to a damaged portion of the conduit. As the bladder is inflated, the repair material is pressed against the inner surface of the conduit wall. Finally, the resin is cured. Curing can be achieved in a number of ways, including but not limited to using hot water, steam, resistive heating, or infrared and ultraviolet radiation.

Preferably the material structure 410 is substantially cylindrical (as shown in Figures 9, 7 and 43, 11) to facilitate conformity with the non-linear conduit. The cylindrical structure has an interior diameter 301 oriented about a longitudinal axis 350. However, the material structure is flexible and can be formed by braiding the fibers. A repair material 410 having a braided configuration of fibers 411 is shown in Figure 10, 12. In braiding most, if not all, of the fibers 118, 119

are arranged in a helical pattern (as shown in Figure 11 43). However, triaxial braiding can be used to combine fibers at two different axial or helical angles with a non-helical, longitudinal fiber. Repair materials fabricated by braiding processes offer exceptional ability to conform to irregular conduit geometries.

5 Because a braided repair material is formed with its reinforcing fibers positioned helically rather than perpendicularly to the longitudinal axis of the material structure, these fibers have the ability to change their braid angle 125, and conform simultaneously in both the inside radius and outside radius of a section of a non-linear conduit.

10 Depending on the desired mechanical properties the density of the fiber braid can be varied to pack more fibers into the tubular arrangement to provide an increase in strength. Conversely, if the structural requirements are minimal, the braid density can be adjusted to where the material present in a volumetric area can be reduced. The angle 125 at which the fibers intersect each other,  
15 otherwise known as the braid angle, can also be varied. When the braid angle is increased, the fibers are positioned closer to perpendicular or vertical and the hoop strength of the finished repair material increases. This is desirable for conduits that are required to support a great amount of weight or withstand high internal pressures. The varying mechanical fiber compaction can be used, e.g.,  
20 knitting, weaving and braiding.

Use of braid or similar types of mechanical fiber compaction construction also will facilitate the unlimited lengths of pipe that may be simultaneously repaired.

Figures 8, 8A 9A and 9B 40, 40A, 44A and 44B are cross sectional  
25 representations of the fiber layers of a repair material illustrated in Figures 7 9 and 11 43. Various reinforcing materials can be included in the braided construction to accommodate both performance and cost issues. Figure 8 40 illustrates a combined placement of reinforcing fibers 122, e.g. glass or nylon, with fibers 124 constructed of thermoplastic material. These fibers can be one of  
30 a combination of various engineered thermoplastics. In addition, thermoplastic films 130 may be used. These fibers, films and reinforcing fibers can be



consolidated using any of the aforementioned methods. Figure 8A 40A illustrates repair material **410** comprised of a combination of reinforcing fibers **122** impregnated within a matrix of resin **131**. Various non-electrically fibers can be employed as reinforcement. The fiber construction can be varied as shown in  
5 Figure 9A 44A. The combination of fibers forms the material structure **410**. Additionally Figure 9A 44A also shows a film **130** of thermoplastic material that forms part of the material structure **410**.

Additionally, Figure 9B 44B illustrates that the material can include electrically conductive fibers **120**, for example carbon fibers, in order to cure the  
10 resin and electric current can be caused to flow through the conductive fibers to resistively heat the repair material. The fibers can be a combination of electrically conductive fibers **120**, thermoplastic fibers **124** and non-conductive fibers **122** e.g., polyester, glass, aramid, and quartz fibers. Other combinations and architectures will be apparent to persons skilled in the art.

15 When electrically conductive fibers are used in conjunction with the thermoplastic fibers and films, as illustrated in Figure 9B 44B, resistive heating can be generated. The heat causes the thermoplastic materials to melt and flow, permeating the electrically conductive fibers and other non-electrically conductive fibers. A reinforced thermoplastic composite results when the materials cool and  
20 harden. In this embodiment, the need for liquid thermosetting resin (which phase change solidification may be enhanced by the addition of heat) is eliminated offering unlimited shelf life and ease of handling. Finished composite properties can be customized with the selection of an appropriate thermoplastic matrix and reinforcing fibers.

25 As shown in cross section in Figures 8 and 9A 40 and 44A the repair material can contain fibers having both structural properties **122** and thermoplastic fibers **124**. Alternatively separate bundles of electrically conductive fibers **120** can be co-mingled with bundles of thermoplastic fibers **124** and structural or reinforcing fibers **120** as shown in Figure 9B 44B. In both cases, the  
30 bundles may be braided together to form the repair material.

In another preferred embodiment, the electrically conductive fibers have an exterior layer or coating of electrically conductive fibers than are then braided. In another preferred embodiment, the seamless material structure is formed by knitting the fibers. In knitting, the repair material is produced by inter looping continuous chains of fibers in a circular fashion. An enlarged view of knitted fibers 118 119 120 is shown in Figure 10A 42A. In a rochelle knit, it is possible to introduce the fibers in a basically longitudinal direction. Because the fibers 118 119 are looped in a circular fashion at every stitch, the finished tubular structure is inherently flexible. For example, in one linear inch of fiber stitch, the actual fiber length may be as long as two inches. This allows continuity in the fibers throughout the length as well as allowing the fiber loops to stretch or open up to variances in the conduit geometry. Various reinforcing materials can also be included in the knit construction to accommodate both performance and cost issues. In addition, electrically conductive fibers 120 can be used such that resistive heating is feasible to cure the resin.

In another preferred embodiment, the seamless material structure is formed from a combination of two or more material layers. A first material layer is a seamless, cylindrical tube configured to fit within a second material layer that has a seamless, cylindrical tube configuration. The material layers are formed from an arrangement of fibers, preferably either braided or knitted fibers. The first material layer is nested within the second material layer and then stitch-bonded together with a stitching thread to form the materials structure. Preferably, the stitch-in thread is elastic to further ensure flexibility of the repair material. In addition, electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

Stitch bonding is a method by which different materials can be consolidated into various forms including seamless, tubular products. The consolidating results from either continuous or intermittent stitching or sewing through the various layers materials. Reinforcing fibers can be used and aligned in a helical arrangement to accommodate geometry changes much like a braided composite. Stitch bonding also allows the use of a wider variety of

electrically conductive material formats such as non-woven graphite formed into tapes. These tapes would be introduced into the composite at a helical angle.

In another preferred embodiment, the seamless material structure is formed from a combination of two or more material layers. A first material layer  
5 is a seamless, cylindrical tube configured to fit within a second material layer that also has a seamless, cylindrical tube configuration. The material layers are formed from an arrangement of fibers, preferably either braided or knitted fibers. The first material layer is nested within the second material layer and then needle punched with a needle board to form the material structure. The needle board  
10 has a plurality of needles such that the needles penetrate the first material layer. When needles are driven through the first material layer, varying amounts of fibers from the first material layer are pulled through the cross section of the adjacent second material layer. These fibers effectively bind the material layers together. In addition to consolidation, the fibers also provide reinforcement in the  
15 Z axis, defined as the axis corresponding to the material layer thickness. The characteristics of the repair material, including flexibility, can be altered by varying the force applied to the needle board, the type and number of needles used, and the number of needle penetrations per square inch. In addition electrically conductive fibers can be used such that resistive heating is feasible to  
20 cure the resin.

In another preferred embodiment, an additive adapted to increase the resin viscosity is provided. The additive is mixed with the resin to form a resin-additive mixture whereby the resin viscosity is increased after a period of time has elapsed. The additive should be formulated such that the resin viscosity  
25 does not immediately increase because this could preclude either resin introduction or resin permeation of the repair material. The resin additive adheres to the fibers in the first and second material layers. As a result, the resin additive mixture stabilizes the fibers and the material layers. In addition electrically conductive fibers can be used such that resistive heating is feasible to  
30 cure the resin.

Figures 15A through 15H ~~17A through 17G~~ illustrate the sequential steps of the combined application of curing a foaming chemical reactant proximate to the exterior of underground **100** pipes, with placement of a curable liner on the interior pipe surface. Figure 15A ~~17A~~ is a cross sectional view of a pipe **250**  
5 beneath the ground surface **105** and having an interior diameter **300**. The pipe has a longitudinal axis of orientation **350**. The pipe has an inner wall surface **256**, an exterior wall surface **254** and a wall thickness **251**. Also illustrated is an insertion port **650** for injecting expanding foam reactant at a selected location in relation to the buried pipe. Also shown is the deflated bladder **450** and separate  
10 material structure **410** positioned as an outer liner to the bladder.

Figure 15B ~~17B~~ illustrates the same components within the ground **100**, but with the bladder **450** now inflated and placing the material structure/repair material **410** into near contact with the inner pipe surface **256**. The diameter **301** of the material structure is shown. In this cross sectional view, only a small  
15 portion of the original pipe diameter **300** is not occupied by the inflated bladder and material structure.

It will be appreciated that the bladder **450** is to be inflated to press the structural material **410** into contact with the inner pipe wall **254** and the space shown in the following Figures is for clarity of illustration only.

20 Figure 15C ~~17C~~ illustrates the foaming chemical reactant **600** being injected into the ground **100**. The foam variously expands in all directions, as illustrated by the several vector arrows, creating a force compacting the underground soil, driving away interstitial groundwater and pressing against the outer pipe wall **254** now *reinforced by the inflated bladder 450*. Figure 15D ~~17D~~  
25 illustrates this process with multiple injecting foams, causing the pipe to be substantially encased in the expanding foam **600**, thereby compacting the ground, driving interstitial groundwater, minimizing or filling voids adjacent to the pipe and thereby stabilizing the pipe.

Figure 15E ~~17E~~ illustrates the curing of the foam assisted by electrically  
30 resistive heat created from current within the electrically conductive fibers within the repair material **410**. A portion of the radiating heat travels outward into the

thickness of the pipe wall 251 and into the surrounding ground or foam. The distance or range of significant heat transfer 605 may be less than the area occupied by the foam 600. However, within this area 605, effective curling of the foam can be achieved, thereby effectively encapsulating the pipe wall, while simultaneously installing an interior reinforcing material. (In another embodiment discussed previously herein, the conductive fibers can be contained within the bladder or a protective liner of the bladder separate from any repair material.)

Figures 15F and 15G ~~17F and 17G~~ illustrate a cross sectional area of the invention, illustrating the interior diameter 301 of the repair material 410 containing the inflated bladder 450, the pipe thickness 251, the area 605 of foam cured by the radiant heat, the outer area of foam 600 and the surrounding ground 100.

The present invention also provides methods and apparatus for repairing a section of non-linear pipe such as the junction or interface 400 between two pipes 200 500 as illustrated in Figure 1. A preferred embodiment of the apparatus of the present invention is depicted in Figure 5. In accordance with the invention, the apparatus includes a main body 460 that is positioned in a first conduit 200. The first conduit 200 may be pipe forming a main line of a sewer system. The main line 200 intersects a second conduit or lateral line 500.

Lateral line 500 is shown here in a perpendicular position essentially at a 90 angle to the main line pipe and intersects the main line pipe at the top portion. This condition is typical but may also be arranged in other configurations. For example, the lateral pipe may intersect the main line pipe at  $\pm 45$  and can be located radially anywhere from the nine o'clock position to the 3 o'clock position.

Radial and vertical positioning of the apparatus is achieved remotely using appropriate controls, and communicated to the apparatus through an umbilical 350. The entire assembly 460 is delivered to the point of repair using a winch or similar device (not shown) attached to the unit via cable assemblies 345. Also illustrated are the heatable caul plates 465 and the flange portion of the repair material 411. (It will be appreciated after reading the following paragraphs that

Figure 5 illustrates the repair material in a loaded position within the main body 460 of the apparatus.

Figure 5A provides a cross sectional view of the apparatus depicted in Figure 5, showing the heatable caul plates 465 in a retracted position on an upper portion of the body 460 of the apparatus, thereby affording a minimal cross section and allowing passage into a main line that may contain offsets, protrusions, etc. The caul plates 465 (hereinafter referred to as "wings") are articulated to allow this reduced cross section by the use of hinges 466.

Figure 5A illustrates the loading of the repair material 410 into the apparatus 460 in preparation for insertion at the intersection of the main line and lateral line. Repair material 410 is preferably constructed of a fibrous woven material capable of holding a heat hardenable or formable resin matrix. Material 410 is also constructed of a material that would be expected to include a portion 412 that conforms to the interior geometry of the lateral pipe wall, and be flexible enough to provide a flange face 411 in the main line pipe. (Reference is also made to Figure 6C.) It is shown that the repair material is wrapped around the retractable/inflatable bladder segment 440. In 5C, the method for loading the repair material 410 is also illustrated. Applying a fluid pressure to the body 460 through umbilical 350 pressurizes an inflation device in the form of a bladder 440. This fluid pressure is regulated through the use of electro-pneumatic regulators located in rear housing 461 in the body 460, and controlled remotely through signal wires in umbilical 350. Pressure sensing is accomplished by sending units located within main body and transmitted through umbilical. All of the signal wires in the umbilical terminate at an operator interface control station (not shown). The force required during this step is minimal and sufficient to cause the bladder 440 to rigidize.

The repair material is constructed in such a fashion as to incorporate both the tubular lateral lining portion 412 as well as the flanged area 411 without the undesirable effect of a potentially weak seam at the transition from tubular to planar. With the bladder 440 pressurized, the material 410, which may be pre-impregnated with a resin as described elsewhere in this specification, is wrapped

412 around the extended bladder 440 as shown by the vector arrow 676 and caused to lay flat 411 on the surface of the wings 465. Depending on the structural requirements, layers of material can continue to be plied to achieve the desired strengths. With the lay-up complete, the pressure of the bladder 440 is lowered the material 410 can be inverted into the main body of the apparatus as shown in Figure 5C. The main body contains a spindle 453 capable of rotation that is fixably attached within the body 460 at a posterior location. The spindle is sealed from the atmosphere to the use of o-rings and protrudes slightly from the body to allow attachment of a tool to cause rotation.

10 As shown in Figure 5D, the bladder construction contains an internal tether 451 that is permanently attached to the interior of the bladder at fitting and removably attached to spindle 453 within the main body 460. To invert the bladder 440 and repair material 410 into the main body for safe transport to the repair location, the tether is wound about the spindle causing the bladder to retract. With the repair material loaded into the device, a winch, or similar device  
15 is employed to pull the apparatus to the desired location within the pipeline. A closed circuit television camera (not shown) can be used to assist in determining the correct location and positioning. Once the entire assembly has been satisfactorily located in proximity to the repair area, final positioning commences  
20 via remote control.

Figure 5D shows the internal working of the apparatus. In order to facilitate rotary position, the apparatus contains a powered rotation mechanism located in the rear housing 461. The rotational mechanism is attached to the main body by use of a coupling. The front section 462 of the body 460 contains  
25 a rotary bearing to compliment this action. Skids 472 are attached to both the front 462 and rear 461 sections to afford minimal surface contact with the main line pipe and ease pulling forces required.

Figure 5D illustrates the apparatus used for placement of the flexible bladder 440 at the pipe interface section 400. The apparatus is positioned in  
30 radially and longitudinally within one pipe 200. The lift cylinders can be elevated by hydraulics or compressed air using a suitable medium. The lift cylinders are

firmly attached to the front section 462 and rear section 461 with cylinder rams attached to the main body. When activated, cylinders 473 effectively lift the main body to force the top portion of the caul plate 465 to be in contact with the interior wall of the main line pipe at the area surrounding the lateral pipe opening. As the  
5 main body lifts, actuator arms 474 encounter the main line pipe wall, as depicted in Figure 5D and 5E. In Figure 5E, the actuator arm bearings 474 convert the vertical motion to a lifting motion through a fulcrum attached to the main body. The opposite ends of the actuator arms are position under the wings 465 and cause the wings to unfold and compress the flanged area 411 of the repair  
10 material firmly against the main line pipe walls.

By introducing pressure to the interior of the main body through umbilical, the bladder and repair material is caused to invert into the lateral pipe. Increasing the pressure inside the bladder causes the tubular section of the repair material to conform to the inside geometry of the lateral pipe section.

15 The bladder and the caul plates may be constructed of a temperature resistant material and contain within the outer skin surface, electrically conductive fibers that are employed to produce heat when an electrical current passes through the fibers. The material surrounding the conductive fibers is a flexible, resilient substance such as silicone, fluorosilicone or fluoropolymer.  
20 Electrical wires conduct the electrical energy from remotely stationed, controllable power supplies to the electrically conductive fibers. Heating temperatures may be produced range between 200 F to 400 F depending on the cure requirements of the resin matrix selected for use in the repair material. These temperatures can be achieved in as little as 10 minutes enabling an  
25 extremely fast cure cycle.

In conjunction with the inflation of the bladder into the interior diameter of the pipe interface and the heating of the bladder and caul plate, reactants can be injected into the ground proximate to the interface to compact the soil and stabilize the soils adjacent to the pipe similar to the manner discussed earlier in  
30 regard to Figures 2 through 4B above. The inverted bladder thereby also serves to minimize the infiltration of injected reactant or reaction product into the interior



diameter. Further, it will be readily appreciated that the heat of the bladder, caul plates or liner may be available to radiate through the thickness of the pipe wall to facilitate the cure of the injected reactant. Again, this heat source may also allow the use of reactants that are not effective in the ambient subsurface environment.

An alternate method and apparatus to the inflatable bladder is the utilization of a radially expanding interior support. The support taught by this specification utilizes a tensionable and compressible coil. The coil possesses a memory of its original coil radius. After the compressive means are removed, the coil returns ("relaxes") to its original radius. This characteristic is a property of material elasticity. When subjected to a stress, e.g. tensile or compressive, the dimensions of the material change, i.e., strain. For an elastic material, the strain is recovered when the stress is removed. When properly dimensioned, as taught herein, the interior pipe wall surface retains the coil in a partially tensioned stated, with a residual outer pressing force. This force, like the outward pressure of the inflated bladder, can be used to form a repair liner or surface patch within the pipe. Unlike the bladder, the coil does not impede the flow of liquid through the pipe and can remain in the pipe as a structural support element, as well as a mechanical means to press and cure repair materials such as thermosetting or thermoplastic materials. It can also block the infiltration of injected reactant, or the resulting cured closed cell foams that are also taught by the invention.

The coil apparatus can be constructed in various forms. One embodiment may utilize a resinous plastic material having sufficient elasticity to allow compression without permanent deformation of shape. The material may be constructed to also include electrically conductive fibers or wire that can be connected to either a dc or ac power source to provide resistive or impedance heating (generally termed resistive heating herein). As already discussed herein, the heat may be utilized in curing or shaping thermally responsive materials that may be used in conjunction with this invention.

The coil support structure may also have a fibrous structure that may be impregnated with resinous thermal responsive materials. These materials may

be thermal plastic or thermal setting resins. In the case of thermal setting materials, the ability to provide heat while in a pressed state to the interior pipe wall may shorten the repair cycle. It may also provide for improved repair by minimizing voids between the pipe wall and the material caused by shrinkage during the material cure or setting.

The material may utilize ester or epoxy resin systems that are allowed to partially cure, preferably to a B stage, without significant cross-linking, prior to release of the tension coil energy. At this partially cured stage, the impregnating resin remains malleable to conform to the vagaries of the interior surface of the pipe wall. This will minimize voids or undesired annular spacing remaining between the relaxed support surface and the interior pipe wall. It will be appreciated by persons skilled in the art that a B stage cured resin is at a highly viscous state, substantially able to retain a shape, but sufficiently plastic to be malleable to the irregularities of a contacting surface. As curing progresses to a C stage and to final cure, cross linking of the polymer molecules increases and thereby creating increasing rigidity of the material, resulting in a solid material at completion.

The support structure may also incorporate multiple layers of reinforcement material combined together as a single layer coiled within the interior with minimal overlap (as illustrated in Figure 16B 48B). The multiple layers may be attached by needle punching or mechanical means. Lateral movement of the layers as a result of the coiling process may be contained by the mechanical intra-laminar attachments, thereby enhancing the shape memory, i.e., the recovery of the shape after removal of the stress or tension force. The support structure may also utilize adhesive properties or materials to bind to the pipe wall.

Figure 16A 48A illustrates a cross section of a pipe 250 having an interior diameter of  $D_2$ . Figure 16B 48B illustrates a flexible coil 480 having an outer diameter of  $D_1$  that is larger than the interior diameter of the pipe. Figure 16C 48C illustrates the flexible coil wound into a tighter coil with a new diameter  $D_3$ . This second diameter, achieved by the tighter winding of the coil, is smaller than

the first diameter and the interior diameter of the pipe. This relationship can be expressed as  $D_1 > D_2 > D_3$ .

Figure 16D ~~18D~~ illustrates a prior art method of pipe 250 repair utilizing a tensioned coil 499 that is wrapped around the exterior of the pipe. The method utilizes wrapping a multi-layered coil having a radius smaller than the exterior diameter of the pipe. The coil material possesses memory of its first coil radius. It there for tends to adhere closely to the outer surface of the pipe (the circumference of the pipe having a larger radius than the first radius of the coil). Of course, the coil can only be wrapped around a pipe having a 360° exposed surface. This would require a buried pipe to be excavated for application of such a coil wrapping.

Figure 17 ~~19~~ illustrates a cross section view of a coil 480 in relation to the interior surface 256 of the pipe. Also illustrated are electrically conductive wires or fibers 122 that are surrounded by a B stage ester or epoxy resin matrix 130. The shape memory properties of the coil material matrix cause the outer coil surface 481 to press the resin matrix to the inner pipe surface as shown by vector arrow 640. Also illustrated is a tension support substrate 132 that may comprise a resinous plastic material or a metal or combination of both.

Another embodiment of the invention subject of this specification teaches utilization of internal support with the exterior wrapped tension coil support to create an interior and exterior walled mold. A defect cavity enclosed within the walled mold or "form" can be then injected with repair material. In one embodiment, the repair material can be injected closed cell foam creating chemical reactants. The reactants will be maintained under pressure within the form, thereby creating enhanced density of the foaming reaction products. The pressure or material strength of the repair mold is attributed to the combination of material strength and the tensioned architecture.

Figure 18A ~~20A~~ illustrates a cross sectional view of across the longitudinal pipe axis 350. Figure 18B ~~20B~~ illustrates a cross sectional view of one section of pipe wall along the longitudinal axis 350.

Figure 18A 20A shows the pipe wall 250 having an inner surface wall 256 and an outer surface 254. Within the pipe annulus 301, the tensioned coil 480 support is released and allowed to unwind, resulting in the outer surface of the support pressing radially outward in the direction of the vector arrows 640. It will be appreciated that the radially directed force applied to the inner pipe surface 256 will be substantially uniform around the circumference of the pipe.

The outer surface of the tension support may be coated (not shown) with an adhesive or thermal responsive material, e.g., thermal setting, thermal plastic or a resin chemical reactant. Alternatively, the support material may impregnated with such components. As described elsewhere herein, the tensioned support may also incorporate electrically conductive materials for heating. The outer pipe wall surface 254 is tensioned wrapped with a material 299 similar to the internal tensioned support, i.e., an elastic material with a matrix memory resulting in it contracting to its relaxed radius (being smaller than the radius of the outer pipe wall). The inner surface of the outer wrap, placed in contact with the outer pipe wall, may also have an adhesive coating or coating of a thermal responsive material. The outer wrap also will have a radially inward compressive force illustrated by the vector arrows 641. This compressive force will also be substantially uniform around the circumference of the pipe 250. The outer wrap may also contain electrically conductive materials for heating. The pipe wrapping action is indicated by vector arrow 643. The outer wrap may also have one or more inlets 498 through which expansive foaming chemical reactants may be injected. It will be appreciated that the gap or space shown in Figure 18A 20A between the pipe and each tensioned support is for clarity of illustration only and that the surfaces will be in close contact.

Figure 18B 20B illustrates a cross sectional view of the pipe 250 along the longitudinal axis 350. The inner tensioned support 480 is shown in contact with the inner pipe wall 256. The surface interface 484 may contain a coating or thermal responsive material. The outer wrapped tension support 499 has a similar interface 497 with the outer surface 254 of the pipe wall 250. Figure 18B 20B also illustrates a hole or defect 255 in the pipe wall that is contained with the

VERLINE V-043

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stated, various changes may be made in the shape, size and arrangement of components or adjustments made in the steps of the method without departing from the scope of this invention. For example, equivalent elements may be substituted for those illustrated and described herein and certain features of the invention may be utilized independently of the use of other features, all as would be apparent to one skilled in the art after having the benefit of this description of the invention.

Further modifications and alternative embodiments of this invention will be apparent to those skilled in the art in view of this specification.

VERLINE V-043

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## TITLE

### TENSIONED PIPE SUPPORT

5

## RELATED APPLICATION

This application is a continuation in part of pending application Serial No. 10/770735 entitled "Apparatus and Method for the Repair and Stabilization of Underground Pipes" filed February 3, 2004, and pending application Serial No. 10 10/182,889 entitled "Apparatus, Methods, and Liners for Repairing Conduits" and filed February 2, 2001.

## BACKGROUND OF INVENTION

### 15 1. FIELD OF THE INVENTION

The present invention relates to an "insitu" method to repair underground pipes and conduits to reduce or eliminate ground water infiltration while stabilizing the proximate ground formation surrounding the pipes.

### 2. BACKGROUND OF THE INVENTION

20 The Clean Water Act has mandated that ground water infiltration into our sewer systems be substantially reduced or eliminated. Many methods of repair have been devised over the last thirty years. Some of those repair methods include slip lining, pipe bursting, cured in place pipe lining (CIPP), fold and form thermoplastic lining, spot repairs, as well as the traditional dig and 25 removal/replacement of pipelines.

It is a known fact that the federal interstate highway system has met and in certain cases exceeded its design life by controlling or reducing incidents of pavement collapse, settling and irregular surfaces. This has been achieved with the development of techniques for the injection of grouts or placement of epoxy 30 patches. In addition, the concrete repair industry has developed and refined the utilization of expandable structural closed cell foams to raise, level and stabilize concrete slabs, foundations, pavements and buildings.

The "insitu lining" repair of pipes has been the most effective alternative to pipe "dig and replacement" for many year. Occasionally an existing annular space or void adjacent to the outside surface of the pipe or conduit has been injected with gelatinous grout materials to eliminate water infiltration into the pipe.

5 This repair has been only temporary since the gelatinous material is not dimensionally stabile and often requires later replacement. The grout is not capable of stabilizing the ground around the pipe even if the entire annular space is filled with the gelatinous grout. The lack of stability and support can result in additional stress on the pipe structure, with eventual degradation of the pipe and

10 resulting water infiltration.

Injection of expanding closed cell foams has seldom been used to repair pipes. Where the closed cell foams have been used to level or reinforce pipe sections, there has been migration of the foam into the pipe/conduit joint that, if left in place, can cause an occlusion or blockage. When this migration into the

15 interior diameter of the pipe does occur, a cutting or grinding device must be inserted as a subsequent step to remove the excess foam.

Another issue is the typical foams being used today are polyurethane's which often contain isocyanate, a groundwater contaminant. Some research has been conducted to determine if the closed cell foam chemistry could be used with

20 grout packers. The blowing agents in the foam, however, create a near immediate reaction that will not allow the annular space to be filled with the foam.

There are hybrid polyester/urethanes expandable closed cell foams that could be used and avoid isocyanate. However, these alternate foam formulations have not been well suited to curing in the *ambient* underground soil

25 conditions.

Another method for repair of pipes has been to excavate a damaged pipe section and wrap the outer pipe wall with a high tensile strength material having an elasticity maintaining the band in contact with the pipe. See for example US

30 Patent No. 4,700,752 of Norman C. Fawley. Another method has been to repair or reinforce a pipe section by wrapping the outer pipe wall with a composite material having a multiplicity of high tensile strength filaments encapsulated in a

resin matrix. The wrapping material is manufactured in a coiled structure and installed by deflecting portions of the material into an uncoiled configuration and then wrapping those portions of the material around the pipe. The material may be applied with an adhesive coating on the pipe surface and between each coil layer. See for example Fawley, US. Patent No. 5,683,529 and 5,677,046.

The measure of physical properties of materials relevant to the present invention include ASTM D1621 Compressive Strength, ASTM D790 Flexural Strength, ASTM D1622 Density, ASTM C 273 Shear Strength, ASTM D 2126 Dimensional Stability, ASTM D696 Coefficient of expansion, ASTM D 543 Chemical Resistance, and ASTM D 2842 Water Absorption.

#### SUMMARY OF INVENTION

Insitu pipe repair methods have been developed utilizing techniques for heat assisted cured in place pipe lining ("CIPP") utilizing epoxy repair materials.

This technology has allowed the use of styrene free thermosetting or thermoplastic resins in an impregnated ("prepreg") composite repair material that is cured with an expandable and heatable bladder. Thermoset resins are curable resins that can be introduced or impregnated into a fibrous repair material. The curing of the resin results in a change of phase of the resin from a liquid to a solid. As a solid, the repair material continues to have the fiber structure. This technology has been adapted for use in the repair or sealing of pipes or conduits, including sewer mains and lateral lines, ("pipes) and the junctions or interfaces of multiple pipelines.

This invention teaches the use of this technology in combination with the injection of chemical reactants creating expanding closed cell foam ("foaming liquids") for stabilization of the surrounding ground proximate to the underground pipes. The heat assisted CIPP mechanisms and techniques for interior pipe repair thereby allow the use of more environmentally friendly foaming liquids than feasible in ambient conditions to stabilize the ground surrounding the pipe. The inflated bladder can provide a heat source for curing of the resin of the prepreg repair materials, closed cell foaming liquid resin and limiting resin redistribution,



and a supporting mechanism for maintaining the pipe diameter and to prevent infiltration of the foam or foaming liquid into the pipe interior.

The Invention also teaches use of the expandable bladder alone within the inside diameter of the pipe in combination with the injection of foaming liquids proximate to the exterior of the pipe surface. The invention also teaches use of an expandable and heatable bladder within the inside pipe diameter to assist in the cure of the injected foaming liquids.

The present invention provides for an improved method of stabilizing the adjacent underground soils or formation around the pipe, minimizing ground water infiltration into the pipe, while repairing the host pipe/conduit or connection. The invention also minimizes exfiltration of sewerage from the pipe. Such exfiltration is a problem particularly when the pipe system is fully charged during a rainfall event.

This invention also teaches the use of an elastically coilable and radially outward expandable material to support and repair pipes. The teaching of this invention includes use for the internal repair of the pipe wall. This may be used in conjunction with other embodiments of the Invention such as soil compaction and stabilization using closed cell foam and resin cured pipe wall repair materials.

The invention also teaches use of a exterior tensioned support exerting a radially compressive force that may be used in conjunction with the interior support, an interior inflated bladder, or alone as a heat source combination with heat responsive repair materials.

Other benefits of the invention will also become apparent to those skilled in the art and such advantages and benefits are included within the scope of this invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention. These drawings, together with the general description of the invention given above and

the detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

Figure 1 illustrates a typical sewer pipe and lateral connection.

Figure 2 illustrates typical defects necessitating repair of a sewer pipe and  
5 sewer pipe connection.

Figure 2A represents a cross sectional view of a defective pipe.

Figure 3A illustrates the prior art use of foaming liquids.

Figures 4A and 4B illustrate the use of the inflatable bladder in combination with injection of foaming liquid.

10 Figure 5 illustrates the pipe repair equipment utilized with simultaneous repair of the pipe interior and ground stabilization.

Figures 5A through 5E further illustrate the pipe repair equipment.

Figure 6 illustrates a detail of the woven repair material for a pipe interface repair.

15 Figure 7 illustrates a woven repair material utilized in one embodiment of the invention.

Figures 8 and 8A are cross sectional views of a hybrid woven repair material.

Figures 9A and 9B are additional cross sectional views of other hybrid  
20 fiber woven repair material.

Figure 10 is an illustration of the braided repair material.

Figure 10A is an illustration of a rochelle knlt.

Figure 11 is an illustration of the helically wound repair material.

Figure 12 is an illustration of multiply aligned pipe segments.

25 Figure 12A is an illustration of mis-aligned pipe segments.

Figures 13 and 13A illustrate the realignment of pipe segments utilizing the invention.

Figures 14 and 14A further illustrate the realignment of pipe segments utilizing the invention.

30 Figures 15A through 15H provide a cross sectional view of the operation of one embodiment of the invention.

Figures 16A through 16C illustrate cross sectional views of the tensioned support.

Figure 16D illustrates a prior art method.

Figure 17 illustrates the relationship of the pipe surface to the resin  
5 impregnated tensioned support with electrically conductive fibers for heating.

Figures 18A and 18B illustrate the combined application of internal and external tensioned supports.

#### DETAILED DESCRIPTION OF THE INVENTION

10 The above general description and the following detailed description are merely illustrative of the subject invention and additional modes, advantages and particulars of this invention will be readily suggested to those skilled in the art without departing from the spirit and scope of the invention. The teaching of this invention will be understood to be applicable for both the repair or support of  
15 sewer pipe connecting interface, as well as for linear and non linear pipelines.

Figure 1 illustrates typical underground sewer pipe configuration that can be the object of repair by the method and apparatus of this invention. The pipes comprise a lateral line 500 typically emerging from a single building or home (not shown). The lateral line is installed for gravity drainage 640 into a collector  
20 sewer or sewer main pipe 200 through a connection or connecting interface 400. Sewerage is gravity conveyed 650 through the diameter 300 of the sewer pipe 200. The lateral pipe and the main sewer pipe each has a longitudinal axis 350. However, over time, the orientation of the individual pipe segments may change from the original longitudinal axis, creating a "non linear" pipe. (Reference is  
25 made to Figures 14 and 14A.) Non linear pipe can also, of course, include curved pipe.

The lateral pipeline and the main sewer pipe are typically comprised of separate segments jointed by a male-female type connecting end flange. The female flange component 210 and corresponding male component 211 are  
30 illustrated in Figure 2. It will be appreciated that the sewer pipe system is buried

within the ground 100 beneath the ground surface 105. The system can be accessed through various ports such as manholes (not shown).

Figure 2 is a cross sectional schematic of the sewer pipe 200 along the longitudinal axis 350. The direction of the gravity flow of sewerage is shown by vector arrow 650. The male 211 – female 210 coupling of the separate sewer pipe sections is also illustrated.

Figure 2 illustrates a common problem experienced with sewer pipe systems. Due do a variety of causes, including the aging of the pipe material, ground shifts or settlement, etc., ground water 175 migrates into the sewer pipes 200. This can cause the exfiltration of sewerage into the surrounding soil or ground water, particularly when the sewer lines are heavily charged, such as during a significant rain event. Alternatively, the infiltration of ground water can burden the sewerage treatment system thereby increasing treatment costs or causing inadequate treatment. (In addition to the obvious environmental damages that may result from inadequate sewer treatment, the inadequate treatment may result in fines and other damages being imposed by regulatory agencies.)

The infiltration of ground water often carries particles of the adjacent soil 100 into the sewer system, which can over time result in voids 150 being created surrounding the pipe 200. The creation of voids or increased interstitial spaces results in groundwater collecting proximate to the pipe. This groundwater can then pass, i.e., infiltrate, into the sewer pipe wall 250 through the cracks 240 or holes 255. It can also pass through defects, such as gaps, in the junctions of each pipe segment 210 211.

Figure 2A is a schematic illustration across the longitudinal axis 350 of a section of the damaged sewer pipe 200 beneath the ground surface 105 and adjacent void 150 in surrounding soil 100. Also illustrated are the pipe diameter 300 and cracks 240 and voids 255 through the thickness 251 of the pipe wall 250. The several vector arrows 175 illustrate the flow of ground water from the soil 100 into the void 150 surrounding the pipe 200 and through the cracks 240 and holes 255 within the sewer pipe wall 250. It will be appreciated that the

voids intended to be remedied by the subject invention need not be of the large size depicted in these illustrations. Further, it will be appreciated that the subject invention is not limited to repair holes or cracks in pipes, but can be used to seal connections (or "couplings") between pipe segments, or between pipe lines, e.g.,  
5 a sewer collection pipe and one or more lateral pipes convey waste ("sewerage") from individual residences, etc.

Use of close cell expandable foams have been used to fill subsurface voids in soils, including use to mechanically raise objects supported by the soil. This has been used in foundation leveling, etc., as taught by Patent Nos.  
10 4,567,708, 6,521,673 and 6,634,831. However, this technology has important limitations for use in filling voids surrounding sewer pipes or sealing/repairing pipe defects. One disadvantage is the infiltration of the closed cell foam into the interior pipe diameter (through which sewerage is intended to flow), thereby creating an occlusion that must be mechanically removed to prevent blockage of  
15 the sewage flow. In addition, the expansive pressure of the closed cell foam (useful in filling or compacting the soil particles or interstitial voids within the soil or between the underground soil and the structure, e.g., sewer pipe or lateral collector, to minimize water collection/infiltration), may also further damage the pipe wall.

20 Figure 3A is a schematic illustration across the longitudinal axis 350 wherein closed cell foam 600 is injected from the ground surface 105 through the injection mechanism 650 into the void 150 within the ground 100 adjacent to damaged sewer pipe wall 250. The foam equipment combines static head mixers 650 with a strong insertion device attached to pumps (not shown) located  
25 at the ground surface 105. The cross section view illustrates the closed cell foam filling the void 150 and infiltrating into the diameter 300 of the sewer pipe 200 through the holes 255 and cracks 240 within the pipe wall 250. The infiltrating foam is shown to create obstructions 337 338 339 within the pipe diameter 300. It will be appreciated that the foam may not fill the entire void 150, perhaps due  
30 to the presence of entrapped ground water (not shown), thereby allowing for the continued collection of ground water proximate to the repaired pipe. The

migration of foam into the pipe can ultimately block the pipe diameter 300 unless a cutter/grinder unit (not shown) is inserted into the pipe and the occlusion is removed. It will be appreciated that it is desirable to avoid this time consuming and expensive step.

5 One embodiment of the apparatus and methods taught in this specification is the advantageous use of techniques for installing a thermally responsive pipe repair material (thermoset or thermoplastic impregnated liner) within the interior diameter of a sewer pipe *in combination with* injection of expanding closed cell foam proximate to the outer diameter of the sewer pipe. The repair material for  
10 the interior pipe diameter may be of a variety of structures, including a structure being defined as an arrangement of fibers such that the repair material has similar dimensions as the pipe diameter or pipe interface to be repaired or sealed. The arrangement of fibers further allows the repair material to be flexible and seamless. Figure 7 9 illustrates an example of a woven structure 410 having  
15 a longitudinal axis 350. In the illustration, fibers 118 119 are intersecting at a variable angles 125. It will be appreciated that the composition of fibers and fiber architecture can be varied, as shown in the cross sectional illustrations along the axis AA in Figures 8, 8A, 9A and 9B discussed later. In a preferred embodiment utilizing the repair material, the material includes a resin having a viscosity. An  
20 additive may be provided to alter the resin viscosity. It will be appreciated that it may be advantageous to increase resin viscosity to retard resin redistribution within the fiber repair material or fiber liner prior to and during the installation process.

A flexible and inflatable bladder is inserted within the pipe diameter. The  
25 bladder serves as a mold to press and hold the repair material to the interior surface of the pipe during the repair process. The inflated bladder, which, in an alternate embodiment of the invention, can be used without the resin impregnated repair material or liner, also minimize the migration of the chemical reactant or resulting foam injected into the underground soils proximate to the  
30 pipe. The migration of chemical reactants or foam can result in occlusion or

obstruction of the pipe diameter. This would obviously hinder the flow of sewerage through the pipe.

The fibrous construction of the repair material, or the components of the inflatable bladder, can include conductive fibers, e.g., carbon fibers, that can be connected to an electrical power source. These conductive fibers, when powered with electric current, may provide electrically resistive or impedance heating (termed herein as "resistive heating") directly through or immediately proximate to the thermosetting resin contained in the repair material. The combined and concurrent pressing of the resin impregnated fibers to the inner pipe wall surface with the heating of the thermosetting resin allows an improved repair and support. The addition of heat, in contrast to ambient conditions, allows more rapid curing. Further, this allows the bladder to remain in place as a mold pressing the repair material for a greater portion of the cure and minimizes the degradation of the repair by resin redistribution. It will be appreciated that the use of the expanding and heatable bladder also minimizes the formation of "annulae" between the interior pipe wall surface and the liner.

Further, heat from the bladder or repair material is also available to radiate through the thickness of the pipe wall to facilitate to the cure of the foaming liquid exterior to the pipe wall. Curing of the foam creates a phase change in the foam to a closed cell solid. The closed cell foamed solid can compact the underground proximate to the pipe, decrease voids or interstitial space containing infiltrating ground water, as well as support and seal the pipe and pipe junctions.

The availability of the proximate heat source also allows use of alternate foaming agents, particularly agents not containing isocyanates. It will be appreciated that isocyanates are considered to be a source of environmental contamination. These alternate reactants include hybrid polyurethane or polyester/polyurethane blend resin, and epoxy resins combined with diluents, catalysts, blowing agents and surfactants, an acrylimide, and cementitious slurry.

Figure 4A is a schematic cross sectional illustration along the longitudinal axis 350 illustrating an embodiment of the method and apparatus of the invention by placing a flexible and inflatable heating bladder 450 inside the pipe diameter

300. The bladder is placed in the area of the pipe having holes 255 or cracks 240 in the pipe wall 250. In this manner, the inflated bladder can provide support to the damaged pipe and facilitate maintaining the pipe diameter 300 during the repair process. The bladder may have resistively heatable sub-components to facilitate the curing of the chemical reactant injected proximate to the exterior pipe wall surface 254.

Figure 4B is a schematic illustration across the longitudinal axis 350 of the pipe after inflation of the bladder 450. The bladder, if used as a heat source, may assist in the curing of the closed cell foam. It will restrain the injectible chemical reactant and resulting foam 600 from permeating the pipe through coupling connectors (211 210 of Figure 2) or cracks 240 or holes 255 in the pipe wall 250. The migration of foam is illustrated in Figure 3A by the multiple vector arrows. The liner 410 (not shown) may be placed over the bladder for reinforcement or to minimize binding of the bladder to the cured foam.

An embodiment of the invention includes the use of resistive energy as a source of heat for curing the injected chemical reactant, as well as to block the migration into the pipe diameter. This heat curing can be accomplished in combination with the placement of a resin impregnated ("prepreg") repair material within the pipe diameter. As mentioned above, the repair material or the flexible bladder may contain electrically conductive fibers. Alternatively, the fiber can be a combination of electrically conductive fibers and non-conductive fibers, which include polyester, glass, aramid, and quartz fibers, and thermoplastic fibers such as, but not limited to polypropylene, nylon and polyethylene.

The repair process is illustrated in Figures 4A, 4B and Figures 15A-H where one skilled in the respective arts observes that there are similarities in both systems, which require 50 K.W. generators and 150 CFM compressors and various cables and hoses. The present invention demonstrates the synergies between the two systems, which eliminates boiler trucks, and on site mixing and impregnation of repair material.

An alternative embodiment that can be used alone or in conjunction with the bladder is inserting an elastically coilable and radially expandable material.



This can be of differing materials, including metal. Important features will be the elasticity, high strength and shape memory, thereby allowing the material to be wound into a tighter coil with a more compact diameter or shorter radius and expansively returning to its original shape. Upon release of the winding energy,  
5 the material relaxes and returns to its original coil diameter. This relaxed diameter will be greater than the internal pipe diameter, thereby causing a relative uniform radial outward pressure force.

It will be appreciated that the mechanism will maintain an open annulus within the pipe thereby allowing the continued passage of fluids through the pipe.  
10 Of course this can permit the relaxed coil to remain in place during the curing process, and thereafter without interruption of service.

This invention addresses the cause and repair of connection offsets or misalignment of pipes and conduits. The misalignment of an originally installed linear pipe may result from faulty bedding surrounding the pipe, which is not  
15 tested as it is in pressure pipe/conduit situations, and ultimately can crack or offset the joints after the pipeline is back-filled. Another cause of misalignment is the result of the movement of ground water as already discussed. While some may contend this method is redundant and more costly, one skilled in the art will easily recognize the efficiencies and safety elements of the present invention

20 This embodiment of the invention provides methods of repairing the misalignment of pipe sections **250A** such as that shown in Figure **12A** **44A**. In this case, the non-linear conduit is buried below the ground surface **105** predominantly in a horizontal orientation as part of a pipe network, e.g., sewer system. The non-linear pipe consists of separate pipe or conduit segments **25A**,  
25 **25B**, **25C**, **25D**, **25E**, **25F**, **25G** that have moved from the original longitudinal axis **350** illustrated in Figure 12 to a non congruous longitudinal orientation **351** and thus does not follow a strictly linear path.

The embodiment of the method taught by this Invention comprises providing the inflatable bladder dimensioned to fit within the interior diameter **300**  
30 of the pipe **250A**, and particularly each non-congruous pipe segment **25A**, **25B**, **25C**, **25D**, **25E**, **25F**, **25G**. The bladder is dimensioned so as, when inflated,

presses against the interior surface of each damaged, e.g. mis-aligned, cracked or broken, section of conduit. The bladder can be made of any strong flexible material. It will be appreciated that it may be advantageous to fit the bladder with one or more layers of protective outer sleeves or liners ("liners"). The liners can provide a repair material (sometime referred to as "material structure") as discussed elsewhere herein, but may also provide protection to the bladder from sharp or jagged surfaces within the conduit sections. The bladder may be filled/infated with fluid, such as water or air, and the effectiveness of the bladder would be compromised if the bladder was punctured.

Figure 13 and 13A illustrate an embodiment of the invention wherein the bladder 450 is placed within the diameter 300 of several mis-aligned pipe segments 25A, 25B, 25C, 25D, 25E, 25F, 25G beneath the ground surface 105. Figure 13 illustrates the bladder with several pipe segments 25B 25E removed for clarity of illustration. The original or intended longitudinal axis of orientation 350 is also shown. It will be appreciated that the mis-alignment may be in any of the three axes of orientation (X, Y, Z).

Figure 14 illustrates the next step of the repair method. Multiple chemical reactant insertion ports 650 are installed from the ground surface 105 to a desired location proximate to the pipe. In the illustrated situation, the ports are installed to be beneath the mis-aligned pipe segments 25B, 25C, 25D, 25E, 25F. The goal of the repair is to push the pipe segments into closer alignment with the longitudinal axis 350. A chemical reactant is injected through the ports into the ground 100 creating the expanding foam 600. Figure 14A illustrates the result of the injection of expanding thermosetting foam 600, causing pipe segments 25B, 25C, 25D, 25E, 25F to be pushed upward as shown by vector arrow 675. The inflatable bladder 450 acts as a flexible mold having a control or guiding function in the realignment of the pipe sections, particularly with regard to the continuity of the pipe diameter 300 and common longitudinal axis of orientation 350.

As suggested by the Figures 12 through 14A, substantial length of pipe can be simultaneously repaired by the invention. The length of inflatable and heatable bladder is not limited. Lengths of pipe extending from one access

manhole to a second manhole may easily be simultaneously repaired by a single use of the method and apparatus of the invention.

Based upon the foregoing disclosure, it will be readily appreciated that the above method can be combined with the embodiment utilizing a repair material  
5 liner impregnated or containing a curing thermosetting or thermoplastic material to seal the pipe from the interior diameter. The repair material structure may be defined by a plurality of fibers such that the repair material is flexible and seamless. This structure is sometimes referred to as a woven "preform".

The resin may be in the form of prepreg fibers or as a resin matrix  
10 surrounding the woven structure. The resin can be a polyester resin, a vinylester resin, a urethane polyester resin, a urethane-vinylester resin, an epoxy resin of a polyurethane resin. The resin is introduced into the repair material by either injection or infusion depending on the type of resin utilized.

A flexible and seamless repair material is able to adapt and conform to of  
15 the interior repair material will neither bind nor wrinkle to cause obstructions to material flow in the conduit. The construction and selection of the repair material also allows it to be used in conjunction with the inflatable bladder. The repair material may be placed as an outer liner on the deflated bladder.

Next, the repair material and bladder is placed in the conduit in close  
20 proximity to a damaged portion of the conduit. As the bladder is inflated, the repair material is pressed against the inner surface of the conduit wall. Finally, the resin is cured. Curing can be achieved in a number of ways, including but not limited in using hot water, steam, resistive heating, or infrared and ultraviolet radiation.

25 Preferably the material structure 410 is substantially cylindrical (as shown in Figures 7 and 11) to facilitate conformity with the non-linear conduit. The cylindrical structure has an interior diameter 301 oriented about a longitudinal axis 350. However, the material structure is flexible and can be formed by braiding the fibers. A repair material 410 having a braided configuration of fibers  
30 411 is shown in Figure 10. In braiding most, if not all, of the fibers 118 119 are arranged in a helical pattern (as shown in Figure 11). However, triaxial braiding

can be used to combine fibers at two different axial or helical angles with a non-helical, longitudinal fiber. Repair materials fabricated by braiding processes offer exceptional ability to conform to irregular conduit geometries. Because a braided repair material is formed with its reinforcing fibers positioned helically rather than perpendicularly to the longitudinal axis of the material structure, these fibers have the ability to change their braid angle **125**, and conform simultaneously in both the inside radius and outside radius of a section of a non-linear conduit.

Depending on the desired mechanical properties the density of the fiber braid can be varied to pack more fibers into the tubular arrangement to provide an increase in strength. Conversely, if the structural requirements are minimal, the braid density can be adjusted to where the material present in a volumetric area can be reduced. The angle **125** at which the fibers intersect each other, otherwise known as the braid angle, can also be varied. When the braid angle is increased, the fibers are positioned closer to perpendicular or vertical and the hoop strength of the finished repair material increases. This is desirable for conduits that are required to support a great amount of weight or withstand high internal pressures. The varying mechanical fiber compaction can be used, e.g., knitting, weaving and braiding.

Use of braid or similar types of mechanical fiber compaction construction also will facilitate the unlimited lengths of pipe that may be simultaneously repaired.

Figures 8, 8A 9A and 9B are cross sectional representations of the fiber layers of a repair material illustrated in Figures 7 and 11. Various reinforcing materials can be included in the braided construction to accommodate both performance and cost issues. Figure 8 illustrates a combined placement of reinforcing fibers **122**, e.g. glass or nylon, with fibers **124** constructed of thermoplastic material. These fibers can be one of a combination of various engineered thermoplastics. In addition, thermoplastic films **130** may be used. These fibers, films and reinforcing fibers can be consolidated using any of the aforementioned methods. Figure 8A illustrates repair material **410** comprised of a combination of reinforcing fibers **122** impregnated within a matrix of resin **131**.

Various non-electrically fibers can be employed as reinforcement. The fiber construction can be varied as shown in Figure 9A. The combination of fibers forms the material structure 410. Additionally Figure 9A also shows a film 130 of thermoplastic material that forms part of the material structure 410.

5        Additionally, Figure 9B illustrates that the material can include electrically conductive fibers 120, for example carbon fibers, in order to cure the resin and electric current can be caused to flow through the conductive fibers to resistively heat the repair material. The fibers can be a combination of electrically conductive fibers 120, thermoplastic fibers 124 and non-conductive fibers 122  
10        e.g., polyester, glass, aramid, and quartz fibers. Other combinations and architectures will be apparent to persons skilled in the art.

When electrically conductive fibers are used in conjunction with the thermoplastic fibers and films, as illustrated in Figure 9B, resistive heating can be generated. The heat causes the thermoplastic materials to melt and flow,  
15        permeating the electrically conductive fibers and other non-electrically conductive fibers. A reinforced thermoplastic composite results when the materials cool and harden. In this embodiment, the need for liquid thermosetting resin (which phase change solidification may be enhanced by the addition of heat) is eliminated offering unlimited shelf life and ease of handling. Finished composite properties  
20        can be customized with the selection of an appropriate thermoplastic matrix and reinforcing fibers.

As shown in cross section in Figures 8 and 9A the repair material can contain fibers having both structural properties 122 and thermoplastic fibers 124. Alternatively separate bundles of electrically conductive fibers 120 can be co-  
25        mingled with bundles of thermoplastic fibers 124 and structural or reinforcing fibers 120 as shown in Figure 9B. In both cases, the bundles may be braided together to form the repair material.

In another preferred embodiment, the electrically conductive fibers have an exterior layer or coating of electrically conductive fibers than are then braided.  
30        In another preferred embodiment, the seamless material structure is formed by knitting the fibers. In knitting, the repair material is produced by inter looping

continuous chains of fibers in a circular fashion. An enlarged view of knitted fibers 118 119 120 is shown in Figure 10A. In a rochelle knit, it is possible to introduce the fibers in a basically longitudinal direction. Because the fibers 118 119 are looped in a circular fashion at every stitch, the finished tubular structure is inherently flexible. For example, in one linear inch of fiber stitch, the actual fiber length may be as long as two inches. This allows continuity in the fibers throughout the length as well as allowing the fiber loops to stretch or open up to variances in the conduit geometry. Various reinforcing materials can also be included in the knit construction to accommodate both performance and cost issues. In addition, electrically conductive fibers 120 can be used such that resistive heating is feasible to cure the resin.

In another preferred embodiment, the seamless material structure is formed from a combination of two or more material layers. A first material layer is a seamless, cylindrical tube configured to fit within a second material layer that has a seamless, cylindrical tube configuration. The material layers are formed from an arrangement of fibers, preferably either braided or knitted fibers. The first material layer is nested within the second material layer and then stitch-bonded together with a stitching thread to form the materials structure. Preferably, the stitch-in thread is elastic to further ensure flexibility of the repair material. In addition, electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

Stitch bonding is a method by which different materials can be consolidated into various forms including seamless, tubular products. The consolidating results from either continuous or intermittent stitching or sewing through the various layers materials. Reinforcing fibers can be used and aligned in a helical arrangement to accommodate geometry changes much like a braided composite. Stitch bonding also allows the use of a wider variety of electrically conductive material formats such as non-woven graphite formed into tapes. These tapes would be introduced into the composite at a helical angle.

In another preferred embodiment, the seamless material structure is formed from a combination of two or more material layers. A first material layer

is a seamless, cylindrical tube configured to fit within a second material layer that also has a seamless, cylindrical tube configuration. The material layers are formed from an arrangement of fibers, preferably either braided or knitted fibers. The first material layer is nested within the second material layer and then needle  
5 punched with a needle board to form the material structure. The needle board has a plurality of needles such that the needles penetrate the first material layer. When needles are driven through the first material layer, varying amounts of fibers from the first material layer are pulled through the cross section of the adjacent second material layer. These fibers effectively bind the material layers  
10 together. In addition to consolidation, the fibers also provide reinforcement in the Z axis, defined as the axis corresponding to the material layer thickness. The characteristics of the repair material, including flexibility, can be altered by varying the force applied to the needle board, the type and number of needles used, and the number of needle penetrations per square inch. In addition  
15 electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

In another preferred embodiment, an additive adapted to increase the resin viscosity is provided. The additive is mixed with the resin to form a resin-additive mixture whereby the resin viscosity is increased after a period of time  
20 has elapsed. The additive should be formulated such that the resin viscosity does not immediately increase because this could preclude either resin introduction or resin permeation of the repair material. The resin additive adheres to the fibers in the first and second material layers. As a result, the resin additive mixture stabilizes the fibers and the material layers. In addition  
25 electrically conductive fibers can be used such that resistive heating is feasible to cure the resin.

Figures 15A through 15H illustrate the sequential steps of the combined application of curing a foaming chemical reactant proximate to the exterior of underground 100 pipes, with placement of a curable liner on the interior pipe  
30 surface. Figure 15A is a cross sectional view of a pipe 250 beneath the ground surface 105 and having an interior diameter 300. The pipe has a longitudinal

axis of orientation **350**. The pipe has an inner wall surface **256**, an exterior wall surface **254** and a wall thickness **251**. Also illustrated is an insertion port **650** for injecting expanding foam reactant at a selected location in relation to the buried pipe. Also shown is the deflated bladder **450** and separate material structure **410** positioned as an outer liner to the bladder.

Figure 15B illustrates the same components within the ground **100**, but with the bladder **450** now inflated and placing the material structure/repair material **410** into near contact with the inner pipe surface **256**. The diameter **301** of the material structure is shown. In this cross sectional view, only a small portion of the original pipe diameter **300** is not occupied by the inflated bladder and material structure.

It will be appreciated that the bladder **450** is to be inflated to press the structural material **410** into contact with the inner pipe wall **254** and the space shown in the following Figures is for clarity of illustration only.

Figure 15C illustrates the foaming chemical reactant **600** being injected into the ground **100**. The foam variously expands in all directions, as illustrated by the several vector arrows, creating a force compacting the underground soil, driving away interstitial groundwater and pressing against the outer pipe wall **254** now reinforced by the inflated bladder **450**. Figure 15D illustrates this process with multiple injecting foams, causing the pipe to be substantially encased in the expanding foam **600**, thereby compacting the ground, driving interstitial groundwater, minimizing or filling voids adjacent to the pipe and thereby stabilizing the pipe.

Figure 15E illustrates the curing of the foam assisted by electrically resistive heat created from current within the electrically conductive fibers within the repair material **410**. A portion of the radiating heat travels outward into the thickness of the pipe wall **251** and into the surrounding ground or foam. The distance or range of significant heat transfer **605** may be less than the area occupied by the foam **600**. However, within this area **605**, effective curing of the foam can be achieved, thereby effectively encapsulating the pipe wall, while simultaneously installing an interior reinforcing material. (In another embodiment



discussed previously herein, the conductive fibers can be contained within the bladder or a protective liner of the bladder separate from any repair material.)

Figures 15F and 15G illustrate a cross sectional area of the invention, illustrating the interior diameter **301** of the repair material **410** containing the  
5 inflated bladder **450**, the pipe thickness **251**, the area **605** of foam cured by the radiant heat, the outer area of foam **600** and the surrounding ground **100**.

The present invention also provides methods and apparatus for repairing a section of non-linear pipe such as the junction or interface **400** between two pipes **200 500** as illustrated in Figure 1. A preferred embodiment of the  
10 apparatus of the present invention is depicted in Figure 5. In accordance with the invention, the apparatus includes a main body **460** that is positioned in a first conduit **200**. The first conduit **200** may be pipe forming a main line of a sewer system. The main line **200** intersects a second conduit or lateral line **500**. Lateral line **500** is shown here in a perpendicular position essentially at a 90  
15 angle to the main line pipe and intersects the main line pipe at the top portion. This condition is typical but may also be arranged in other configurations. For example, the lateral pipe may intersect the main line pipe at  $\pm 45^\circ$  and can be located radially anywhere from the nine o'clock position to the 3 o'clock position.

Radial and vertical positioning of the apparatus is achieved remotely using  
20 appropriate controls, and communicated to the apparatus through an umbilical **350**. The entire assembly **460** is delivered to the point of repair using a winch or similar device (not shown) attached to the unit via cable assemblies **345**. Also illustrated are the heatable caul plates **465** and the flange portion of the repair material **411**. (It will be appreciated after reading the following paragraphs that  
25 Figure 5 illustrates the repair material in a loaded position within the main body **460** of the apparatus.

Figure 5A provides a cross sectional view of the apparatus depicted in Figure 5, showing the heatable caul plates **465** in a retracted position on an upper portion of the body **460** of the apparatus, thereby affording a minimal cross  
30 section and allowing passage into a main line that may contain offsets,

protrusions, etc. The caul plates **465** (hereinafter referred to as "wings") are articulated to allow this reduced cross section by the use of hinges **466**.

Figure 5A illustrates the loading of the repair material **410** into the apparatus **460** in preparation for insertion at the intersection of the main line and lateral line. Repair material **410** is preferably constructed of a fibrous woven material capable of holding a heat hardenable or formable resin matrix. Material **410** is also constructed of a material that would be expected to include a portion **412** that conforms to the interior geometry of the lateral pipe wall, and be flexible enough to provide a flange face **411** in the main line pipe. (Reference is also made to Figure 6C.) It is shown that the repair material is wrapped around the retractable/inflatable bladder segment **440**. In 5C, the method for loading the repair material **410** is also illustrated. Applying a fluid pressure to the body **460** through umbilical **350** pressurizes an inflation device in the form of a bladder **440**. This fluid pressure is regulated through the use of electro-pneumatic regulators located in rear housing **461** in the body **460**, and controlled remotely through signal wires in umbilical **350**. Pressure sensing is accomplished by sending units located within main body and transmitted through umbilical. All of the signal wires in the umbilical terminate at an operator interface control station (not shown). The force required during this step is minimal and sufficient to cause the bladder **440** to rigidize.

The repair material is constructed in such a fashion as to incorporate both the tubular lateral lining portion **412** as well as the flanged area **411** without the undesirable effect of a potentially weak seam at the transition from tubular to planar. With the bladder **440** pressurized, the material **410**, which may be pre-impregnated with a resin as described elsewhere in this specification, is wrapped **412** around the extended bladder **440** as shown by the vector arrow **676** and caused to lay flat **411** on the surface of the wings **465**. Depending on the structural requirements, layers of material can continue to be plied to achieve the desired strengths. With the lay-up complete, the pressure of the bladder **440** is lowered the material **410** can be inverted into the main body of the apparatus as shown in Figure 5C. The main body contains a spindle **453** capable of rotation

that is fixably attached within the body 460 at a posterior location. The spindle is sealed from the atmosphere to the use of o-rings and protrudes slightly from the body to allow attachment of a tool to cause rotation.

As shown in Figure 5D, the bladder construction contains an internal  
5 tether 451 that is permanently attached to the interior of the bladder at fitting and removably attached to spindle 453 within the main body 460. To invert the bladder 440 and repair material 410 into the main body for safe transport to the repair location, the tether is wound about the spindle causing the bladder to retract. With the repair material loaded into the device, a winch, or similar device  
10 is employed to pull the apparatus to the desired location within the pipeline. A closed circuit television camera (not shown) can be used to assist in determining the correct location and positioning. Once the entire assembly has been satisfactorily located in proximity to the repair area, final positioning commences via remote control.

15 Figure 5D shows the internal working of the apparatus. In order to facilitate rotary position, the apparatus contains a powered rotation mechanism located in the rear housing 461. The rotational mechanism is attached to the main body by use of a coupling. The front section 462 of the body 460 contains a rotary bearing to compliment this action. Skids 472 are attached to both the  
20 front 462 and rear 461 sections to afford minimal surface contact with the main line pipe and ease pulling forces required.

Figure 5D illustrates the apparatus used for placement of the flexible bladder 440 at the pipe interface section 400. The apparatus is positioned in radially and longitudinally within one pipe 200. The lift cylinders can be elevated  
25 by hydraulics or compressed air using a suitable medium. The lift cylinders are firmly attached to the front section 462 and rear section 461 with cylinder rams attached to the main body. When activated, cylinders 473 effectively lift the main body to force the top portion of the caul plate 465 to be in contact with the interior wall of the main line pipe at the area surrounding the lateral pipe opening. As the  
30 main body lifts, actuator arms 474 encounter the main line pipe wall, as depicted in Figure 5D and 5E. In Figure 5E, the actuator arm bearings 474 convert the

vertical motion to a lifting motion through a fulcrum attached to the main body. The opposite ends of the actuator arms are position under the wings 465 and cause the wings to unfold and compress the flanged area 411 of the repair material firmly against the main line pipe walls.

5 By introducing pressure to the interior of the main body through umbilical, the bladder and repair material is caused to invert into the lateral pipe. Increasing the pressure inside the bladder causes the tubular section of the repair material to conform to the inside geometry of the lateral pipe section.

10 The bladder and the caul plates may be constructed of a temperature resistant material and contain within the outer skin surface, electrically conductive fibers that are employed to produce heat when an electrical current passes through the fibers. The material surrounding the conductive fibers is a flexible, resilient substance such as silicone, fluorosilicone or fluoropolymer. Electrical wires conduct the electrical energy from remotely stationed,  
15 controllable power supplies to the electrically conductive fibers. Heating temperatures may be produced range between 200 F to 400 F depending on the cure requirements of the resin matrix selected for use in the repair material. These temperatures can be achieved in as little as 10 minutes enabling an extremely fast cure cycle.

20 In conjunction with the inflation of the bladder into the interior diameter of the pipe interface and the heating of the bladder and caul plate, reactants can be injected into the ground proximate to the interface to compact the soil and stabilize the soils adjacent to the pipe similar to the manner discussed earlier in regard to Figures 2 through 4B above. The inverted bladder thereby also serves  
25 to minimize the infiltration of injected reactant or reaction product into the interior diameter. Further, it will be readily appreciated that the heat of the bladder, caul plates or liner may be available to radiate through the thickness of the pipe wall to facilitate the cure of the injected reactant. Again, this heat source may also allow the use of reactants that are not effective in the ambient subsurface  
30 environment.

An alternate method and apparatus to the inflatable bladder is the utilization of a radially expanding interior support. The support taught by this specification utilizes a tensionable and compressible coil. The coil possesses a memory of its original coil radius. After the compressive means are removed, the coil returns ("relaxes") to its original radius. This characteristic is a property of material elasticity. When subjected to a stress, e.g. tensile or compressive, the dimensions of the material change, i.e., strain. For an elastic material, the strain is recovered when the stress is removed. When properly dimensioned, as taught herein, the interior pipe wall surface retains the coil in a partially tensioned state, with a residual outer pressing force. This force, like the outward pressure of the inflated bladder, can be used to form a repair liner or surface patch within the pipe. Unlike the bladder, the coil does not impede the flow of liquid through the pipe and can remain in the pipe as a structural support element, as well as a mechanical means to press and cure repair materials such as thermosetting or thermoplastic materials. It can also block the infiltration of injected reactant, or the resulting cured closed cell foams that are also taught by the invention.

The coil apparatus can be constructed in various forms. One embodiment may utilize a resinous plastic material having sufficient elasticity to allow compression without permanent deformation of shape. The material may be constructed to also include electrically conductive fibers or wire that can be connected to either a dc or ac power source to provide resistive or impedance heating (generally termed resistive heating herein). As already discussed herein, the heat may be utilized in curing or shaping thermally responsive materials that may be used in conjunction with this invention.

The coil support structure may also have a fibrous structure that may be impregnated with resinous thermal responsive materials. These materials may be thermal plastic or thermal setting resins. In the case of thermal setting materials, the ability to provide heat while in a pressed state to the interior pipe wall may shorten the repair cycle. It may also provide for improved repair by minimizing voids between the pipe wall and the material caused by shrinkage during the material cure or setting.

The material may utilize ester or epoxy resin systems that are allowed to partially cure, preferably to a B stage, without significant cross-linking, prior to release of the tension coil energy. At this partially cured stage, the impregnating resin remains malleable to conform to the vagaries of the interior surface of the pipe wall. This will minimize voids or undesired annular spacing remaining between the relaxed support surface and the interior pipe wall. It will be appreciated by persons skilled in the art that a B stage cured resin is at a highly viscous state, substantially able to retain a shape, but sufficiently plastic to be malleable to the irregularities of a contacting surface. As curing progresses to a C stage and to final cure, cross linking of the polymer molecules increases and thereby creating increasing rigidity of the material, resulting in a solid material at completion.

The support structure may also incorporate multiple layers of reinforcement material combined together as a single layer coiled within the interior with minimal overlap (as illustrated in Figure 16B). The multiple layers may be attached by needle punching or mechanical means. Lateral movement of the layers as a result of the coiling process may be contained by the mechanical intra-laminar attachments, thereby enhancing the shape memory, i.e., the recovery of the shape after removal of the stress or tension force. The support structure may also utilize adhesive properties or materials to bind to the pipe wall.

Figure 16A illustrates a cross section of a pipe 250 having an interior diameter of  $D_2$ . Figure 16B illustrates a flexible coil 480 having an outer diameter of  $D_1$  that is larger than the interior diameter of the pipe. Figure 16C illustrates the flexible coil wound into a tighter coil with a new diameter  $D_3$ . This second diameter, achieved by the tighter winding of the coil, is smaller than the first diameter and the interior diameter of the pipe. This relationship can be expressed as  $D_1 > D_2 > D_3$ .

Figure 16D illustrates a prior art method of pipe 250 repair utilizing a tensioned coil 499 that is wrapped around the exterior of the pipe. The method utilizes wrapping a multi-layered coil having a radius smaller than the exterior

diameter of the pipe. The coil material possesses memory of its first coil radius. It there for tends to adhere closely to the outer surface of the pipe (the circumference of the pipe having a larger radius than the first radius of the coil). Of course, the coil can only be wrapped around a pipe having a 360° exposed  
5 surface. This would require a buried pipe to be excavated for application of such a coil wrapping.

Figure 17 illustrates a cross section view of a coil 480 in relation to the interior surface 256 of the pipe. Also illustrated are electrically conductive wires or fibers 122 that are surrounded by a B stage ester or epoxy resin matrix 130.

10 The shape memory properties of the coil material matrix cause the outer coil surface 481 to press the resin matrix to the inner pipe surface as shown by vector arrow 640. Also illustrated is a tension support substrate 132 that may comprise a resinous plastic material or a metal or combination of both.

Another embodiment of the invention subject of this specification teaches  
15 utilization of internal support with the exterior wrapped tension coil support to create an interior and exterior walled mold. A defect cavity enclosed within the walled mold or "form" can be then injected with repair material. In one embodiment, the repair material can be injected closed cell foam creating chemical reactants. The reactants will be maintained under pressure within the  
20 form, thereby creating enhanced density of the foaming reaction products. The pressure or material strength of the repair mold is attributed to the combination of material strength and the tensioned architecture.

Figure 18A illustrates a cross sectional view of across the longitudinal pipe axis 350. Figure 18B illustrates a cross sectional view of one section of pipe  
25 wall along the longitudinal axis 350.

Figure 18A shows the pipe wall 250 having a inner surface wall 256 and an outer surface 254. Within the pipe annulus 301, the tensioned coil 480 support is released and allowed to unwind, resulting in the outer surface of the support pressing radially outward in the direction of the vector arrows 640. It will  
30 be appreciated that the radially directed force applied to the inner pipe surface 256 will be substantially uniform around the circumference of the pipe.

The outer surface of the tension support may be coated (not shown) with an adhesive or thermal responsive material, e.g., thermal setting, thermal plastic or a resin chemical reactant. Alternatively, the support material may impregnated with such components. As described elsewhere herein, the tensioned support  
5 may also incorporate electrically conductive materials for heating. The outer pipe wall surface **254** is tensioned wrapped with a material **299** similar to the internal tensioned support, i.e., an elastic material with a matrix memory resulting in it contracting to its relaxed radius (being smaller than the radius of the outer pipe wall). The inner surface of the outer wrap, placed in contact with the outer pipe  
10 wall, may also have an adhesive coating or coating of a thermal responsive material. The outer wrap also will have a radially inward compressive force illustrated by the vector arrows **641**. This compressive force will also be substantially uniform around the circumference of the pipe **250**. The outer wrap may also contain electrically conductive materials for heating. The pipe wrapping  
15 action is indicated by vector arrow **643**. The outer wrap may also have one or more inlets **498** through which expansive foaming chemical reactants may be injected. It will be appreciated that the gap or space shown in Figure 18A between the pipe and each tensioned support is for clarity of illustration only and that the surfaces will be in close contact.

20 Figure 18B illustrates a cross sectional view of the pipe **250** along the longitudinal axis **350**. The inner tensioned support **480** is shown in contact with the inner pipe wall **256**. The surface interface **484** may contain a coating or thermal responsive material. The outer wrapped tension support **499** has a similar interface **497** with the outer surface **254** of the pipe wall **250**. Figure 18B  
25 also illustrates a hole or defect **255** in the pipe wall that is contained with the tension inner and outer supports. This void or "repair cavity" **255** may be filled by material injected through the injection port **498** via a pipe or hose **605**. The inner and outer tensioned support will have sufficient strength to contain the foam reactant. Due to the confined fixed volume of this repair cavity, the injected  
30 reactant (not shown) may achieve increased density that if permitted unrestricted expansion.



While specific embodiments have been illustrated and described, numerous modification are possible without departing from the spirit of the invention, as the scope of protection is only limited by the scope of the accompany claims.

5        This specification is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the manner of carrying out the invention. It is to be understood that the forms of the invention herein shown and describe are to be taken as the presently preferred embodiments. As already stated, various changes may be made in the shape, size and arrangement of  
10 components or adjustments made in the steps of the method without departing from the scope of this invention. For example, equivalent elements may be substituted for those illustrated and described herein and certain features of the invention may be utilized independently of the use of other features, all as would be apparent to one skilled in the art after having the benefit of this description of  
15 the invention.

Further modifications and alternative embodiments of this invention will be apparent to those skilled in the art in view of this specification.